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TECHNICAL REPORT

R.B. Nelson, B.E. Morris
and
J.W. McGarvey

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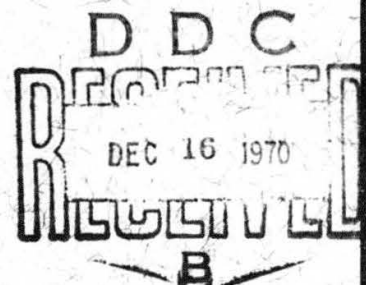
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ABSTRACT

Shock-wave propagation and focusing theories were investigated in the U. S. Army Weapons Command Science and Technology Laboratory to determine the feasibility of utilizing shock waves for military applications. The propagation of hypothetical weak shock-waves with small planar or concave frontal areas was analyzed on the basis of Whitham's shock-wave theory. The results indicate that shock waves with these characteristics cannot be propagated intact over militarily significant distances. The general applicability of Whitham's theory to this problem is questionable, however, in view of experimental data in the literature which indicate that very weak shock waves can be effectively focused. Therefore, these discrepancies should be experimentally resolved to explicitly define the feasibility of military applications of shock waves.

CONTENTS

OBJECTIVE

The objective was to investigate shock wave propagation and focusing theories to determine the feasibility of utilizing shock waves for military applications.

INTRODUCTION

For certain military applications, it would be desirable to focus shock waves or shocked sound-waves into a finite area at a significant distance from a source such as a detonation tube. Consequently, this investigation was initiated to study the feasibility of accomplishing a concentration of shock-wave strength or of eliminating the normal geometric dilution of shock-wave strength associated with shock-wave propagation.

An approximate theory of shock-wave dynamics developed by Whitham[1] has been applied to predictions of strong shock-wave diffraction and stability problems with general success. For shocks with low Mach number, however, the theory does not appear to be quite as satisfactory in the prediction of observed shock-wave diffraction behavior.[2] Nevertheless, the Whitham theory appears to be generally accepted as an analytical working model for the prediction of dynamic shock-wave behavior.

Recent data obtained in studies of N-wave focusing have indicated that weak shocks may behave according to the principles of geometrical acoustics.[3] This point would seem to be quite significant since the focusing behavior predicted by geometrical acoustics is markedly different from that predicted by the Whitham theory. These differences will be considered later in the report. However, the shock-wave pressure amplitudes used in the N-wave study were pertinent to sonic boom phenomena, and the largest amplitude used was of the order of one one-hundredth of the amplitude of interest here. This point also would seem to be quite significant since the realms of classical acoustics and nonlinear shock phenomena are separated largely on the basis of pressure amplitude.

The feasibility of shock-wave focusing was primarily considered in terms of Whitham's theory since it is believed that this theory should best describe the behavior of shocks having peak overpressures in excess of one psi. Some implications of the geometrical acoustic theory on shock focusing are also made later in the report, however. Focusing in the usual acoustic sense, in which rays converge at a point, is not necessarily required for many military applications.

All that is required is to concentrate the major portion of energy produced by a generator into a given area at some distance away. This could conceivably be accomplished by properly shaping the wave front as it emerges from the generator or by some focusing device external to the generator. The acoustical power output of the generator is generally distributed over some area (as opposed to a point source). Consequently, if it is desired to concentrate this energy in an area of a few square meters at a significant distance from the generator with minimal spreading losses, the shape of the wave front should be essentially planar or possibly concave. The general approach taken in this investigation was that of analyzing the propagation of planar and concave shock-wave fronts to provide insight into establishing the feasibility of directing shock waves.

THEORY, DISCUSSION, AND RESULTS

I. Planar Shock Waves

A. Formation of Planar Shock Waves

Planar shock waves are formed in a detonation tube or in a shock tube because shock waves propagating down a channel become oriented normal to the channel walls. A diffraction process takes place upon exit of the shock wave from the end of the tube, however, and the details of this diffraction depend on the geometry of the tube exit.

Diffraction of shock waves has been investigated by Whitham and by Skews.[1,2] Predictions of the shape of planar shock waves diffracting around convex corners were made by Skews based on the approximate theory of Whitham. The results of these predictions were compared with experimental results for corner angles varying from 15° to 165°. The theoretical and the experimental results were generally in good agreement, and the typical two-dimensional behavior observed is shown in Figure 1. In general, a disturbance on the initial planar shock originating at the corner spreads out on the planar shock. The final shock configuration consists of a short planar region which is normal to the new wall direction, an expanding curved section, and the remaining portions of the original planar shock. The angle m_o, in Figure 1, represents the angle taken by the point on the incident planar shock where the curvature of the disturbance begins. Skews found that experimentally the angle m_o was
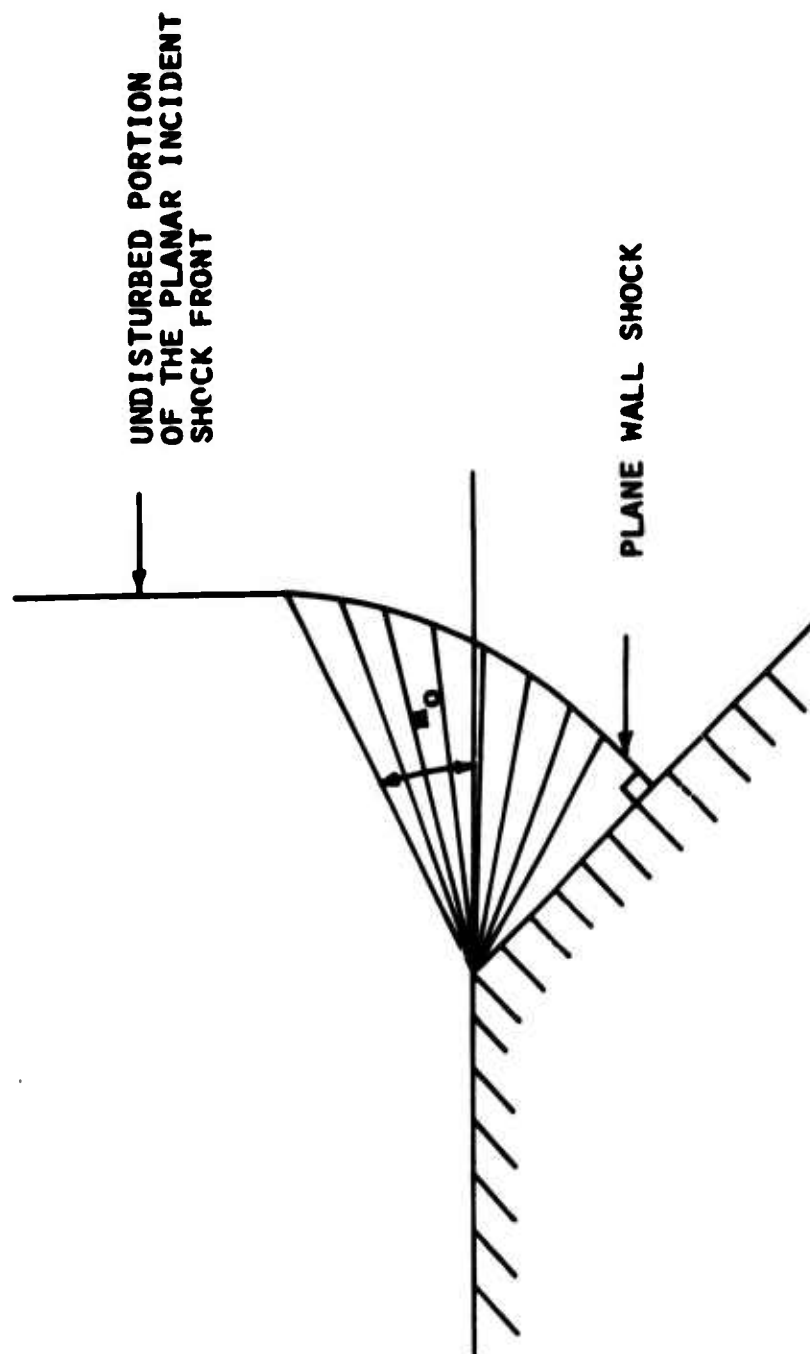
2

UNDISTURBED PORTION
OF THE PLANAR INCIDENT
SHOCK FRONT

PLANE WALL SHOCK

FIGURE 1   SHOCK DIFFRACTION PATTERN AROUND A CONVEX CORNER

given satisfactorily by the derived relation

$$\tan^2 m_0 = (\gamma-1)(M_0^2-1)\{M_0^2 + 2/(\gamma-1)\}/(\gamma+1)M_0^4,$$

where M_0 is the incident shock Mach number and γ is the specific heat ratio. A graph of this relation is shown in Figure 2, with m_0 shown in degrees as a function of M_0.

It is of interest to note in Figure 2 that except for very small values of M_0, m_0 is in excess of 20°. For this reason, a planar shock-wave formed in a tubelike device cannot be transferred to the atmosphere intact. Instead, as the shock emerges from the tube exit, diffraction occurs, with the curved disturbance shock propagating along the incident shock at an angle m_0 from the tube exit, as illustrated in Figure 1. Since m_0 ranges from 20 to 30 degrees for incident shock Mach numbers from 1.1 to 5.0, the incident planar shock can be expected to be severely degraded at points more than about R cot 20° distant from the tube exit, where R is the tube radius.

The question now arises whether the diffraction losses could be lessened if the detonation chamber exit geometry were somehow modified. As was mentioned earlier, Skews studied the shape of diffracting shock waves for exterior tube angles in the range of 15° to 165°. The diffracted wave shapes remained essentially constant in time, and all were of the general form shown in Figure 1. Thus, it is not apparent that any modification of the tube exit angle can significantly reduce the degradation of the planar wave shape due to diffraction.

The effects on the emerging shock diffraction process of the interior angle of the detonation chamber might also be questioned. However, if a planar shock enters the final section of the detonation tube traveling along the tube axis, a converging or diverging final section would be expected to only strengthen or weaken the shock respectively, prior to its emergence from the section into the atmosphere. When the shock emerges, one would again expect the diffraction effect appropriate to the strength of the shock upon exit from the section. The preceding discussion indicates the reason why a pure planar shock wave of finite area cannot be formed in the atmosphere from such a shock traveling down a tube. If such a wave can be formed by any means whatever, it would apparently have to be done by some process external to the tube which is not subject to diffraction effects, such as propagating a shock wave through a nonuniform medium.
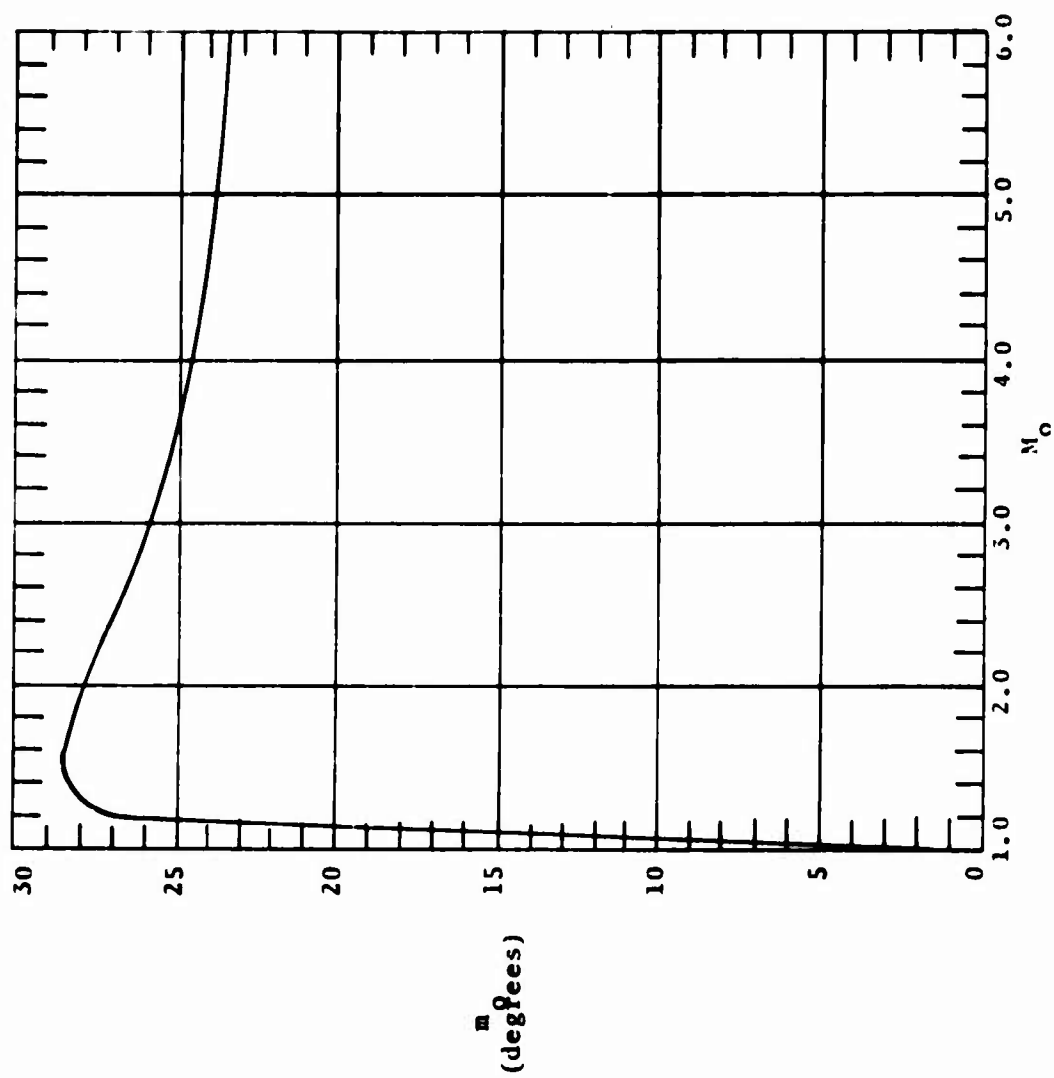
FIGURE 2   PLOT OF $m_o = Tan^{-1} [(\gamma-1)(M_o^2-1) \{M_o^2 + 2/(\gamma-1)\}/(\gamma+1) M_o^4]^{\frac{1}{2}}$

B. Shock-Wave Refraction

A fundamental distinction of shock waves from sound waves is that in a given medium, sound waves propagate at the prevailing sonic velocity, whereas the propagation velocity of shock waves is dependent on the shock strength. However, for a given shock strength and a given medium, shock velocity is directly related to the sonic velocity. Consequently, in a region in which the properties of the medium change in such a way as to change the sonic velocity, the shock wave velocity changes correspondingly, and refraction of either sound or shock waves can take place.

It is well established that under proper conditions, the atmosphere can cause refraction of acoustic or shock waves. This effect can be attributed to the fact that the sound velocity in the atmosphere is temperature-dependent, and also attributed to the effects of atmospheric winds. Thus, the combined variations of temperature and wind velocity with altitude give an effective corresponding variation of sound velocity with altitude. Refraction of sound and shock rays, therefore, occurs. Rays initially parallel to the earth's surface are refracted upward under conditions where the velocity decreases with altitude and rays are refracted downward when velocity increases with altitude. In this way, the atmosphere can act as a lens on shock or sound waves and, under appropriate conditions, can focus or concentrate the shock energy on an area with a resulting significant increase in shock strength.

While it is difficult to imagine a practical application for atmospheric acoustic focusing, the concept of an inhomogeneous refractive medium has been used to direct acoustic energy under water.[4] A spherical focusing device was designed so that the acoustical refractive index varies with the radial distance from the center in the proper manner to collimate or focus acoustic rays entering the device. A potential problem associated with this approach in air is that some means to contain the media with varying refractive index must be used that would have a high density relative to air. The resulting acoustic impedance mismatch could cause a high reflection coefficient for the wave as it impinged on the lens, with a corresponding transmission loss in passing through the lens. The concept of impedance for shock waves is relatively new and apparently no investigations of the feasibility of employing the Luneberg lens for focusing shock waves in air have been reported.[5]

C. Propagation of Planar Shock Fronts

Another question that must be considered relative to the feasibility of directing shock waves is the following: If a planar shock of small finite area could be formed, over what effective distances might it be expected to propagate intact? Some degradation losses at the edges of the shock as it propagated would certainly be expected.

To gain some insight into the extent of such losses on a propagating planar shock wave, a hypothetical problem was formulated and Whitham's theory was used to investigate the subsequent shock behavior.

The two-dimensional version of Whitham's theory associates successive positions of a curved shock moving through a medium by a set of curves. The orthogonal trajectories of these curves are called rays and are analagous to the rays of geometrical acoustics. The set of curves and trajectories corresponding to the movement of a shock through a medium are used as the basis for an orthogonal curvilinear coordinate system so that the shock positions and rays correspond to curves of constant α and constant β, respectively (Figure 3). The basis of the theory is that a shock is always perpendicular to its direction of propagation as it moves in a uniform atmosphere at rest and that the localized shock Mach number is related to the area of the shock front "trapped" between two rays of the shock.

The coordinate α is conventionally taken to be $\alpha = a_o t$, where a_o is the sonic velocity in the undisturbed gas ahead of the shock. The distance along a ray between shocks located at α and $d\alpha$ is then $M(\alpha,\beta)d\alpha$ where M is the Mach number at α,β. Similarly, the corresponding spacing between rays at β, $\beta+d\beta$, is $A(\alpha,\beta)d\beta$. It can be shown that geometrical considerations alone require

that

$$\frac{\partial \theta}{\partial \beta} = \frac{1}{M} \frac{\partial A}{\partial \alpha} \tag{1}$$

and

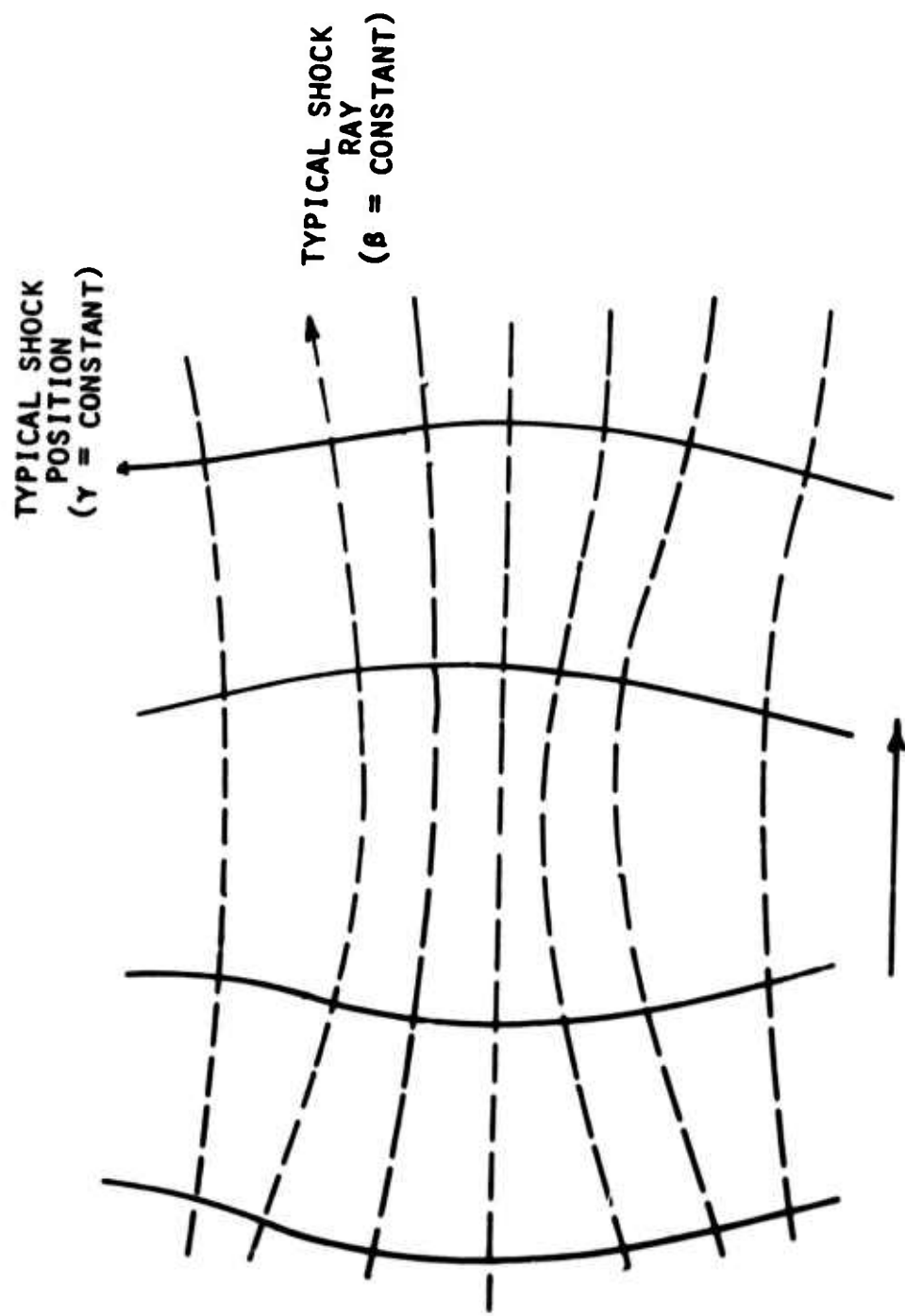$$\frac{\partial \theta}{\partial \alpha} = -\frac{1}{A} \frac{\partial M}{\partial \beta} \tag{2}$$

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TYPICAL SHOCK POSITION (γ = CONSTANT)

TYPICAL SHOCK RAY (β = CONSTANT)

FIGURE 3   SUCCESSIVE POSITIONS OF INITIALLY CONCAVE SHOCK FRONT

8

where $\theta(\alpha, \beta)$ is the angle made by the ray at α, β. The angle θ can be eliminated from the above-cited two equations to give a differential relation between M and A. An additional relation is obtained from consideration of the energy flux down a ray channel. The energy flux is proportional to the square of the pressure amplitude multiplied by the channel area. Within a given channel, the flux is constant so that the strength is proportional to $A^{-\frac{1}{2}}$. For weak shocks, the shock strength is proportional to M-1, so one has

$$M-1 \propto A^{-\frac{1}{2}} \tag{3}$$

as the second relation between M and A that, in principle, allows solution for M as a function of α and β.

In adapting the problem to the computer, Equation (2) was used in the computation of each successive new shock position, while Equation (1) was satisfied indirectly by recalculation of the ray direction normal to the new shock position at each step. The relation

$$M-1 = A^{-\frac{1}{2}} \tag{4}$$

was used to calculate the Mach number corresponding to the area between adjacent rays at each new shock position. A typical FORTRAN IV program used is listed in the Appendix.

The planar problem investigated involved a shock wave propagating out from a wall (Figure 4). The problem is hypothetical in the sense that nothing is said concerning the source of energy driving the shock. The shock has radial symmetry and consists of a central planar section that is five feet in radius, surrounded by a curved section that forms a boundary with the wall. The curved section serves to facilitate the analysis by the avoidance of a discontinuity at the edge of the shock. While it may be argued that the shock is not truly planar, the degradation losses of the shock considered should be less severe than those of a "true planar shock" by virtue of the sharp-pressure discontinuity present at the edge of the latter.

A plot of shock Mach number at the center line as a function of distance from the initial shock position for three different initial shock sizes is illustrated in Figure 5. As can be seen from the figure, the center line Mach number remains constant at the value set in as an initial condition

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DISTANCE TRAVELED (FT.)

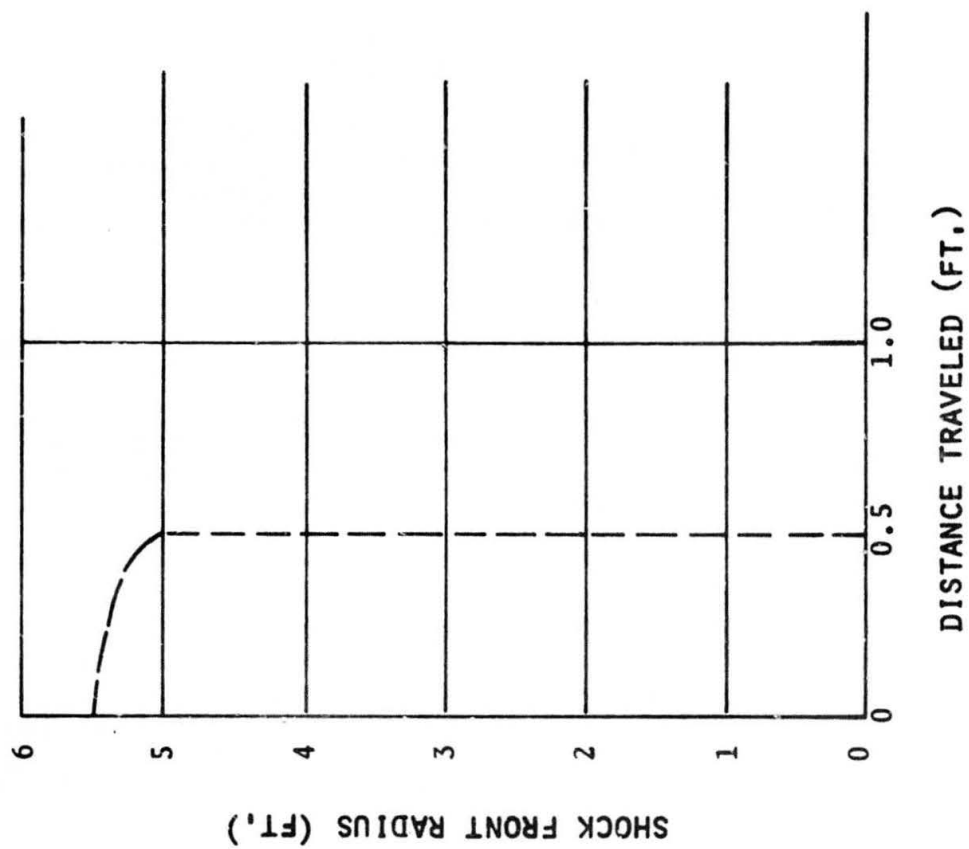SHOCK FRONT RADIUS (FT.)

FIGURE 4   INITIAL HYPOTHETICAL PLANAR CONFIGURATION (time = 0)

DISTANCE TRAVELED (FT.)
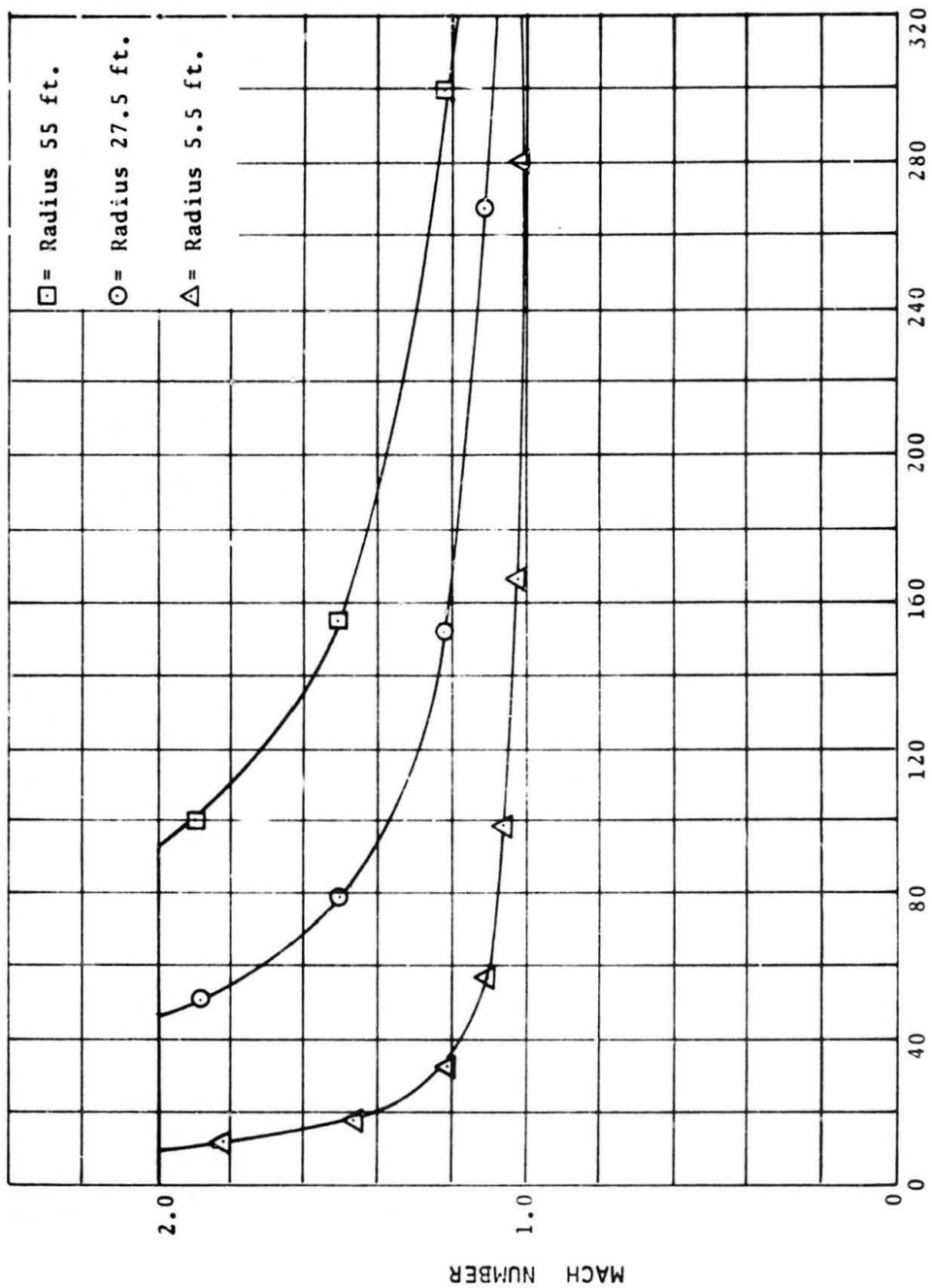
CENTER LINE RESULTS OF PLANAR SHOCK PROPAGATION

☐ = Radius 55 ft.

☉ = Radius 27.5 ft.

△ = Radius 5.5 ft.

MACH NUMBER

FIGURE 5

11

until the wave has propagated a distance approximately 80 per cent of the initial planar section diameter. Beyond this point, the center line Mach number decays quite rapidly with a shape that, at least for the smallest shock, strongly resembles the decay of a spherical blast wave.

The behavior of the shock profile as a whole is depicted in Figure 6. The tendency of the "planar" shock toward a progressively more spherical shape is quite evident.

II. Concave Shock Fronts

A. Analysis Based on Whitham's Theory

The general type of behavior to be expected of a concavity in a shock front, based on Whitham's theory, is indicated in Figure 3. As this figure indicates, formation of a caustic does not occur. Instead, as the front propagates, the rays begin to converge with a resultant strengthening of the front in the region of the concavity. The strengthening in this region increases the velocity there and tends to smooth out the shape so that any intersection of the rays does not occur.

Although focusing in the usual sense of geometric acoustics does not occur, the concavity does subsequently create a region of increased "ray density" that implies a region of increased shock strength. To investigate the potential ranges and relative strengths that could be obtained by virtue of this effect, several shock waves were analyzed having various types and degrees of concavity. The basic method used was similar to that used in the analysis of planar shocks.

The effects of varying degrees of spherically shaped concavity on the center line Mach number as a function of distance from the initial shock position are illustrated in Figure 7. Corresponding center line behavior for an initially planar shock of the same initial size is included for reference purposes. The effects of increased radius of curvature in the concave section are to lower the peak center line Mach number attained and to increase the distance at which the peak occurs. The planar curve apparently can be thought of as representing the limiting case of infinite radius of curvature.

The effects of elliptical, parabolic, and hyperbolic concave curvatures, respectively, on the center line Mach numbers as a function of distance are shown in Figures 8, 9, and 10. As in the spherical case, the general effect of increased curvature was to increase the degree to which the
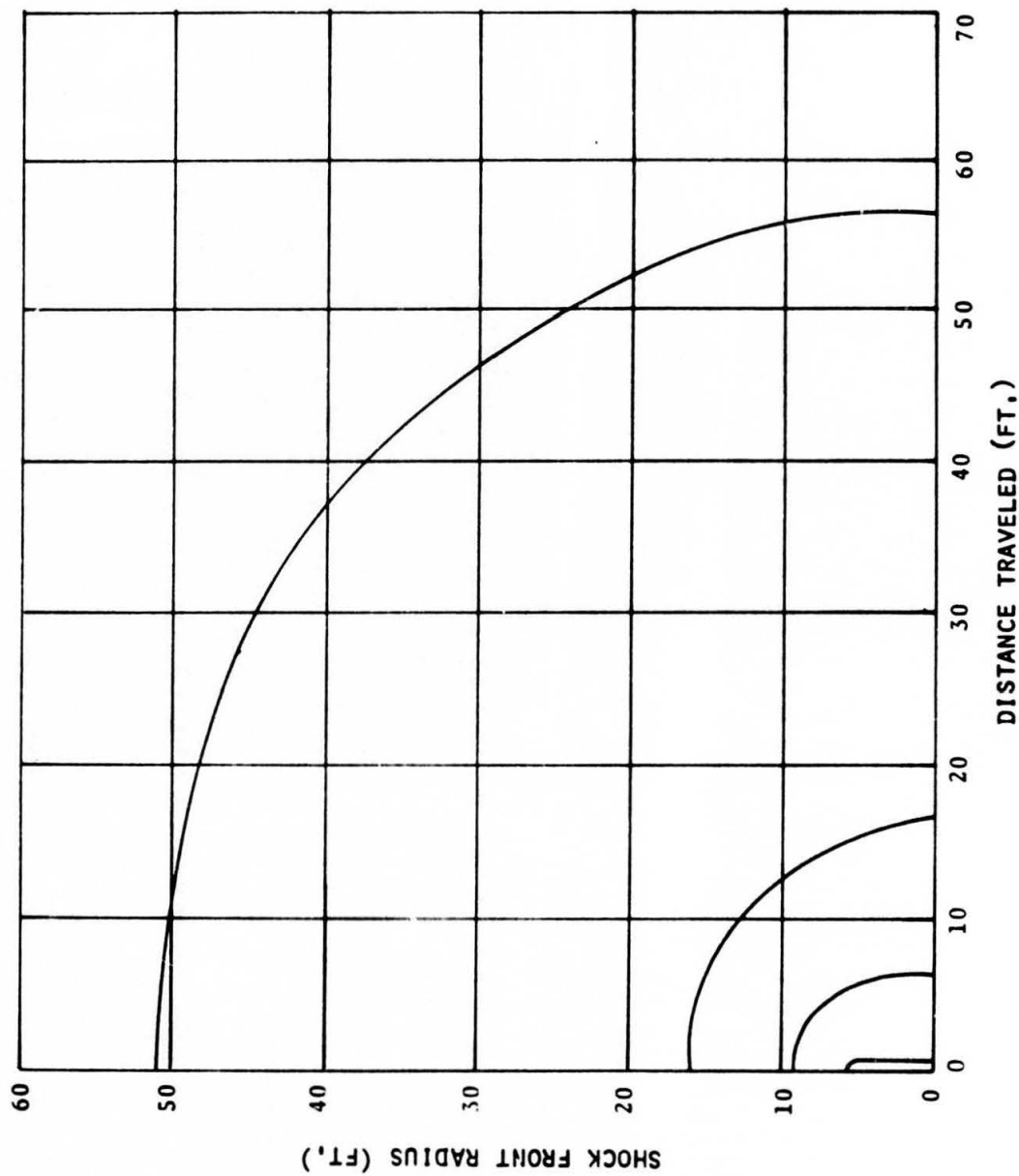
FIGURE 6   SUCCESSIVE PROPAGATED PROFILES OF INITIALLY PLANAR SHOCK WAVE
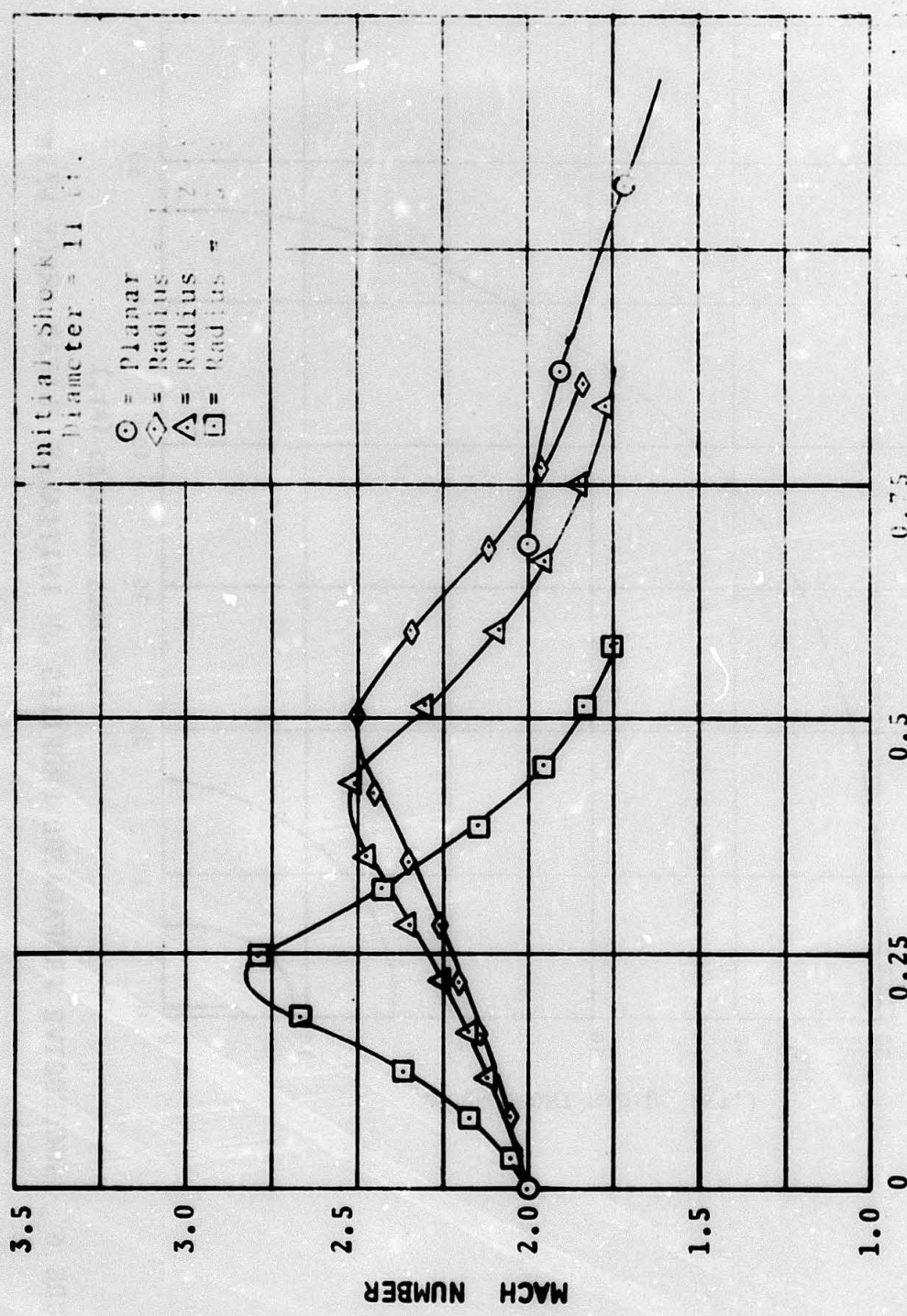
13

DISTANCE TRAVELED IN UNITS OF SHOCK DIAMETER

CENTER LINE RESULTS FOR PROPAGATION
OF INITIALLY SPHERICAL CONCAVE SHOCK

FIGURE 7

14

DISTANCE TRAVELED IN UNITS OF SHOCK DIAMETER

CENTER LINE RESULTS
FOR PROPAGATION OF INITIALLY ELLIPTIC CONCAVE SHOCK

FIGURE 8

15
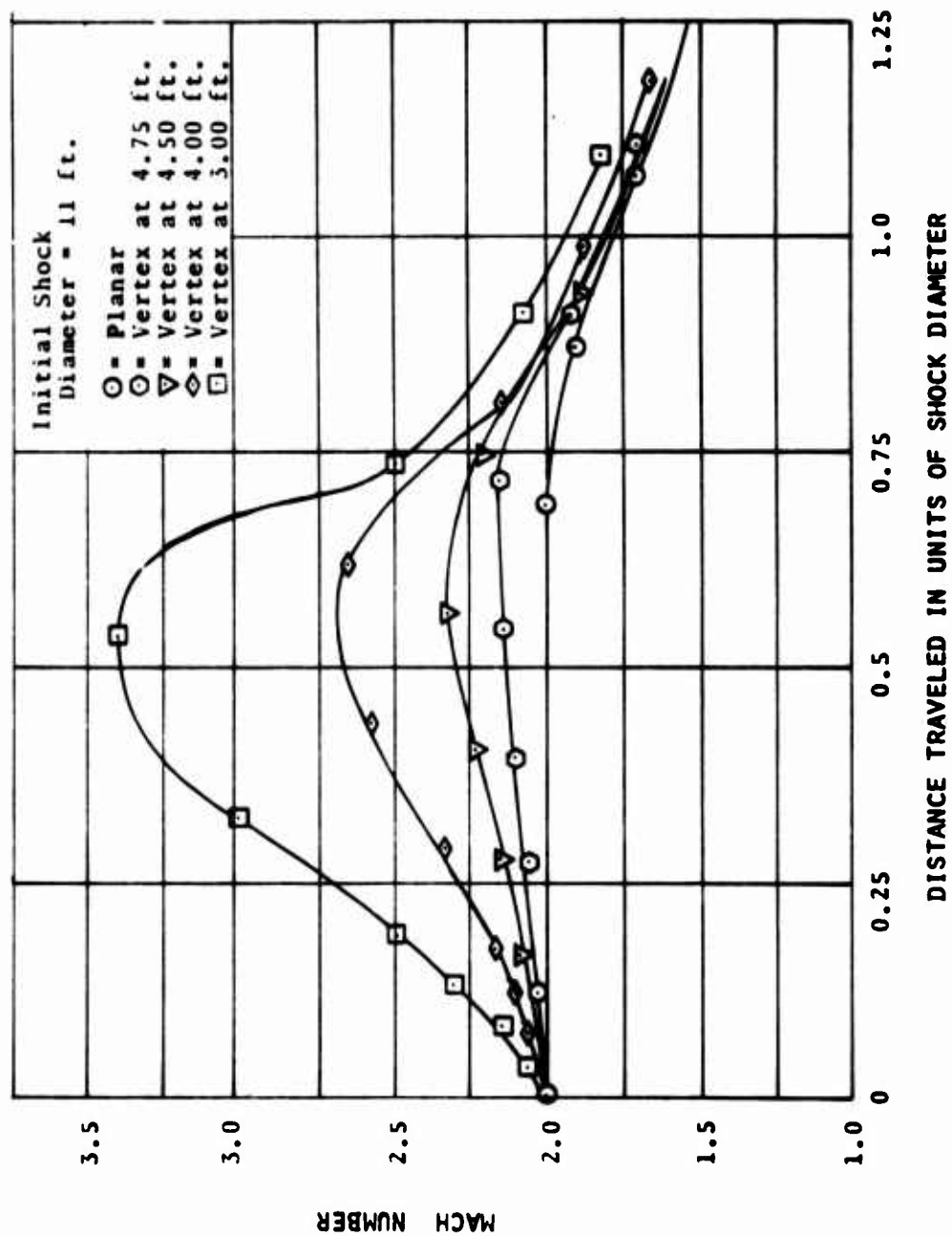
FIGURE 9

CENTER LINE RESULTS
FOR PROPAGATION OF INITIALLY PARABOLIC CONCAVE SHOCK

16

DISTANCE TRAVELED IN UNITS OF SHOCK DIAMETER

CENTER LINE RESULTS FOR PROPAGATION
OF INITIALLY HYPERBOLIC SHOCK

FIGURE 10

17

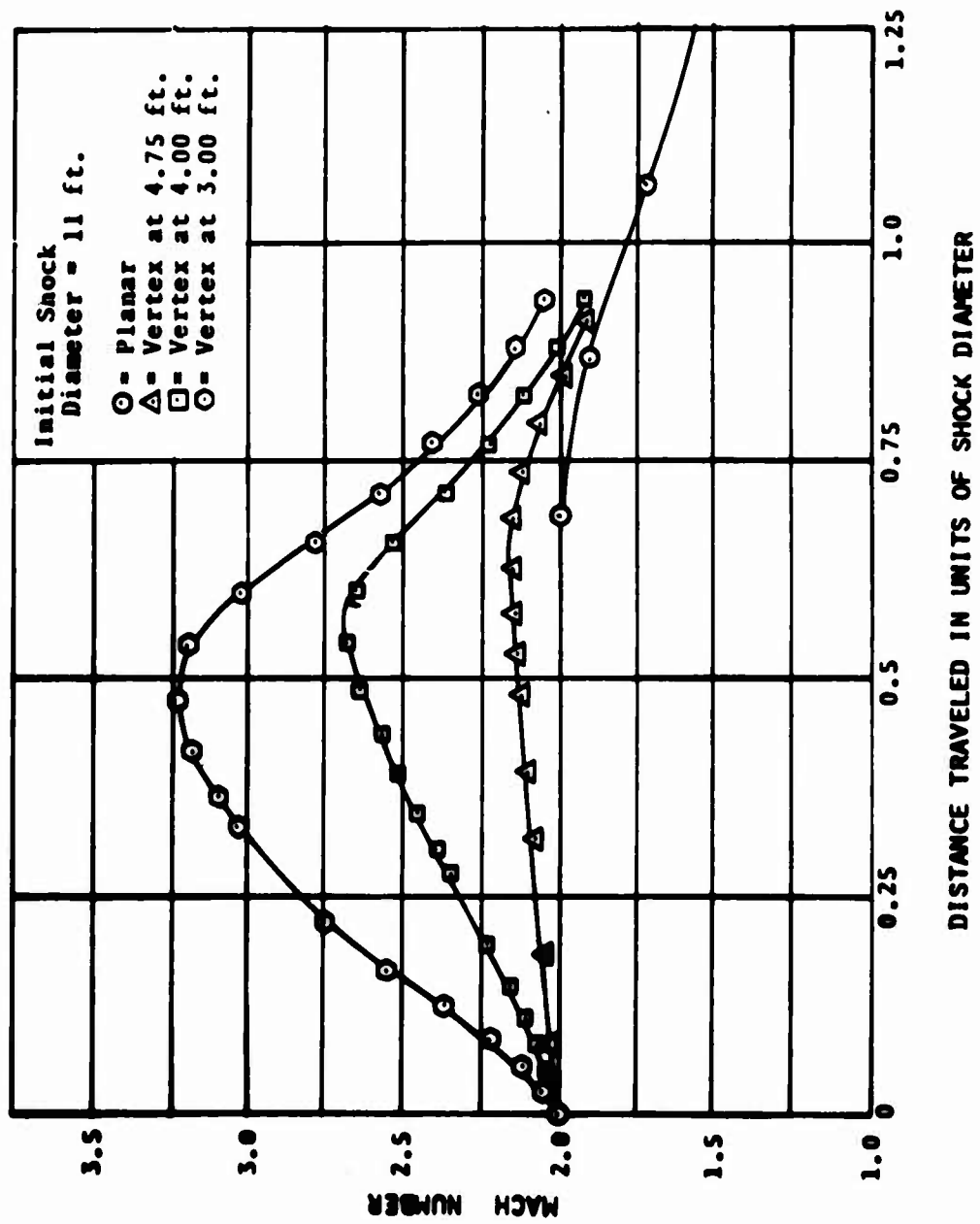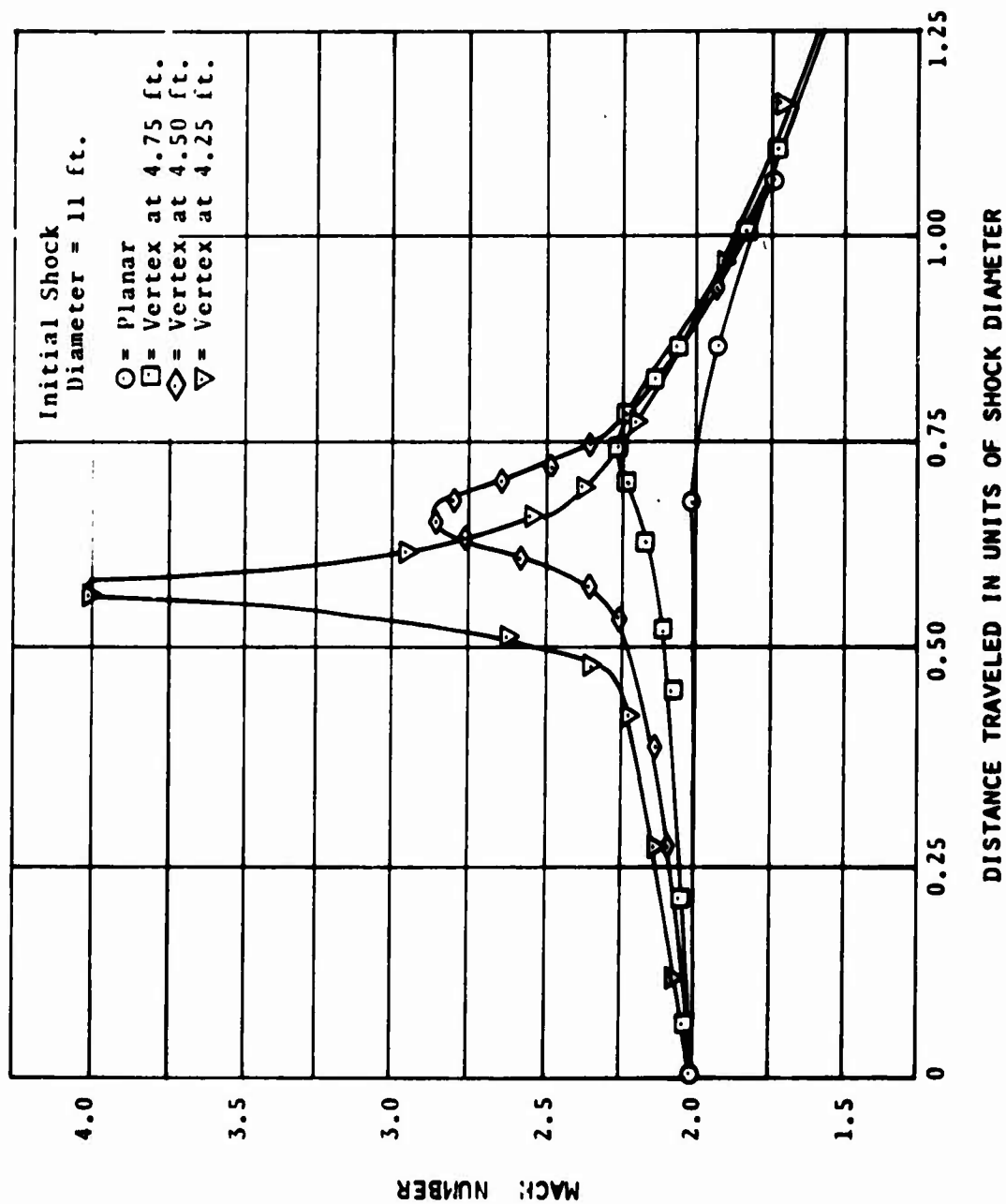Mach number is peaked and to shorten the distance from the initial position at which the peak occurs. The Mach peaks seemed most pronounced for the elliptically shaped initial configurations. In all cases, however, no significant gain in Mach number over that of the initially planar configuration was observed at distances in excess of a few diameters of the initial shock.

B. Experimental Data on Weak Shocks

It was mentioned earlier that recent data reported by Beasley, et.al., relative to the focusing of N-waves has indicated that very weak shocks can be focused according to the principles of geometrical acoustics. The acoustics solution is based on the premise that rays normal to a wave front remain fixed in direction. Consequently, rays normal to a concavity eventually form a caustic, or focus. Beasley's group investigated the focusing behavior of N-waves having amplitudes between 1.48 and 4.61 pounds per square foot and having wavelengths short in comparison to the dimensions of the focusing mirrors used. Their results indicated that, when such shocks were reflected from a focusing mirror, they passed through a line or point focus for the respective two and three dimensional cases, with an accompanying phase reversal. A sequence of Schlieren photographs showing successive stages in the process was included.

The theory of geometrical acoustics and Whitham's theory of shock are basically quite similar in concept. However, the effect of the basic linear premise of geometrical acoustics is to represent all points on a wave front as having the same propagation velocity. This leads to the marked difference in the focusing behavior predicted by the two theories. The fact that very weak shocks apparently conform to the principles of geometric acoustics is quite significant. Yet, at higher amplitudes, the increased deviation of the shock velocity from the implicitly assumed sonic velocity of geometric acoustics must begin to become apparent in focusing. The amplitudes at which these changes in focusing behavior occur and the nature of any transitional focusing phenomena would be a significant contribution to the concept of shock focusing.

CONCLUSIONS AND RECOMMENDATIONS

The propagation of planar and concave shock wave sections was studied on the basis of the shock theory of G. B. Whitham. The results indicate that the feasibility of directing shock waves of small frontal area over significant distances without spreading losses is very much in doubt.

However, experimental data on the focusing of very weak shocks indicate that they do not conform to Whitham's theory. Consequently, it is recommended that the apparent discrepancy in the theory of weak shock focusing behavior be resolved experimentally before a final conclusion is reached on the feasibility of focusing this type of shock wave.

LITERATURE CITED

1. Whitham, G. B., "A New Approach to Problems of Shock Dynamics, Part I - Two Dimensional Problems," *Journal of Fluid Mechanics*, Volume 2, p. 145, 1957.

2. Skews, B. W., "The Shape of a Diffracting Shock Wave," *Journal of Fluid Mechanics*, Volume 29, Part 2, pp. 297-304, 1967.

3. Beasley, W. D., Brooks, J. D., and Barger, R. L., "A Laboratory Investigation of N-Wave Focusing," NASA TND-5306, Langley Research Center, Hampton, Virginia, 1969.

4. Holden, R., "Deep Sea Calibration Results of a Spherical 5 Foot Gaseous Tube Acoustic Lens (U)," North American Aviation, Inc., Autonetics Division, Anaheim, California, 1967 (Confidential).

5. Henderson, L. F., "On Shock Impedance," *Journal of Fluid Mechanics*, Volume 40, Part 4, pp. 719-735, 1970.

APPENDIX

SHOCK WAVE PROPAGATION PROGRAM

```
//PUNCH JOB (0174039,5,5000),'AWCOR-REMOTE-02-SAVE'
C
C                         NOMENCLATURE
C
C         KA      = NUMBER OF FORWARD STEPS FOR SHOCK
C         X(I)    = AXIAL DISTANCE
C         R(I)    = RADIAL DISTANCE
C         M(I)    = MACH NUMBER ON CHORD LINE CONNECTING POINTS I & I+1
C         A(I)    = AREA OF CHORD FRUSTRUM /PI
C         DB(I)   = LENGTH OF CHORD LINE
C         DP(I)   = PRESSURE RISE ASSOCIATED WITH M(I)
C         BS      = SUM OF DB(I)S
C         AVB     = BS/30, THAT IS, INCREMENT LENGTH TO CALCULATE NEXT FORWARD STEP
C         TH      = ANGLE OF SHOCK RAY TO +X DIRECTION
C         DMDB    = RATE OF CHANGE OF MACH NUMBER WITH DISTANCE ALONG CHORD
C         MAV     = AVERAGE MACH NUMBER AT LATTICE POINT
C         THT     = ACTUAL DIRECTION USED TO CALCULATE LOCATION OF NEW POINT,
C                 = THETA +DELTA THETA/2
C         MA = 2.0 DIVIDED BY MACH (1) TO NORMALIZE AVB
C
C
      IMPLICIT REAL*8(A-H,M-Z)
      DOUBLE PRECISION DATAN,DSQRT,DCOS,DSIN,DABS
      DIMENSION X(31),R(31),M(30),A(30),DB(30),DP(30),Y(31),S(31)
      KA = 400
      DO 280 K = 1,KA
C     IF K=1 SET INITIAL VALUES OF X,R,AND M
      IF(K-1)10,10,140
C        SET VALUES OF X, R AND M FOR I = 27 THRU 30
   10 DO 20 I = 1,4
      AI=2*I-1
      R(I+26)=5.D0+0.5D0*DSIN(3.14159D0*AI/20.D0)
      X(27) = 4.9938442D0
      X(28) = 4.9455034D0
      X(29) = 4.8535536D0
      X(30) = 4.7269957D0
   20 M(I+26) = 2.D0 - 0.07777D0*AI
C        SET VALUES OF X AND M FOR I = 1 THRU 26
      DO 30 I = 1,26
      X(I) = 5.0D0
   30 M(I) = 2.D0
      SARC=3.14159D0/36.D0
C        SET VALUES OF R FOR I = 1 THRU 26
      DO 40 I = 1,4
      AI=2*I
   40 R(I+22) = 5.D0 + SARC * (AI - 9.D0)
C        SMOOTH OUT R FOR I = 2 THRU 22
      IS=0
      DO 50 I = 1,22
   50 IS = IS + 1
      AIS=IS
```

```
      ADELT=(R(23)-44.D0*SARC)/AIS
      R(1) = 0.D0
      DO 60 I = 1,21
      AI=I
   60 R(23 - I) = R(24 - I) - 2.D0 * SARC - ADELT*AI
      MP25=(3.D0*M(24)+M(28))/4.D0
      MP27=(3.D0*M(28)+M(24))/4.D0
      M(25)=(M(25)+MP25)/2.D0
      M(27)=(M(27)+MP27)/2.D0
      MP26=(M(24)+M(28))/2.D0
      M(26)=(M(26)+MP26)/2.D0
C        SET FINAL VALUES OF R AND X FOR I = 31
      X(31) = 4.5D0
      R(31)=5.5D0
C        RESET X VALUES FOR SPECIAL SHAPES
   70 DO 80 I = 1,26
      X(I)=DABS(((0.75D0*DSQRT(25.D0-R(I)**2))/5.D0) -5.D0)
   80 CONTINUE
      G=1.4D0
      WRITE (6,90)
   90 FORMAT(84OK =     1)
      WRITE (6,100)
  100 FORMAT('         X              R           MACH.NO.    DELTA PR
     1ESSURE        DB'//)
C        CALCULATE A(I), DB(I), AND DP(I)
      DO 110 I = 1,30
      A(I)=(R(I+1)+R(I))*DSQRT((X(I)-X(I+1))**2+(R(I)-R(I+1))**2)
      DB(I)=DSQRT((X(I)-X(I+1))**2+(R(I)-R(I+1))**2)
      DP(I)=2.D0*G*(M(I)**2-1.D0)/(G+1.D0)
  110 WRITE (6,120)I,X(I),R(I),M(I),DP(I),DB(I)
  120 FORMAT(I4,5D15.8)
      WRITE (6,130)X(31),R(31)
  130 FORMAT(4H  31,2D15.8)
      MA = (2.D0/(5.D0*M(1)))
      GO TO 280
C    CALCULATE FORWARD INCREMENT IN ALPHA
  140 BS = 0.D0
      DO 150 I = 1,30
  150 BS = BS + DB(I)
      IF(K.LE.200)AVB = (BS/300.D0) * MA
      IF(K.GT.200.AND.K.LE.500)AVB = (BS/150.D0) * MA
      IF(K.GT.500.AND.K.LE.1000)AVB = (BS/100.D0) * MA
      IF(K.GT.1000.AND.K.LE.1500)AVB = (BS/50.D0) * MA
      IF(K.GT.1500)AVB = (BS/30.D0) * MA
C    CALCULATE LOCATION OF NEW POINTS
C        REPLACE X AND R VALUES WITH Y AND S DESIGNATIONS
  160 DO 170 I = 1,31
      Y(I)=X(I)
      S(I)=R(I)
  170 CONTINUE
C        CALCULATE TH, DMDB, MAV, THT, AND X(I) AND R(I)
  180 DO 200 I = 2,30
      TH=(DATAN((Y(I-1)-Y(I))/(S(I)-S(I-1)))+DATAN((Y(I)-Y(I+1))
     1/(S(I+1)-S(I))))/2.D0
      DMDB=2.D0*(M(I)-M(I-1))/(DB(I)+DB(I-1))
      MAV=(M(I)*DB(I-1)+M(I-1)*DB(I))/(DB(I)+DB(I-1))
      THT=TH-AVB*MAV*DMDB/2.D0
  190 X(I) = X(I) + AVB * MAV * DCOS(THT)
      R(I) = R(I) + AVB * MAV * DSIN(THT)
  200 CONTINUE
      X(1)=X(2)
```

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```fortran
      R(31)=R(30)+0.001D0
C     R(31) SET LARGER THAN R(30) TO STOP ATAN  ARGUMENT FROM = INFINITY
C         CALCULATE AT, M(I), AI, DB(I), AND DP(I)
  210 DO 230 I = 1,30
      AT=   (R(I+1)+R(I))*DSQRT((X(I)-X(I+1))**2+(R(I)-R(I+1))**2)
  220 M(I) = 1.D0+(M(I)-1.D0) * DSQRT(A(I)/AT)
      A(I)=AT
      DB(I)=DSQRT((X(I)-X(I+1))**2+(R(I)-R(I+1))**2)
  230 DP(I) = 2.D0*G*(M(I)**2 - 1.D0)/(G + 1.D0)
C     WRITE OUT THE WAVE FRONT POSITION AND PROPERTIES
      IF (K.LE.299) GO TO 280
  232 IF((K/10)*10-K)280,240,280
  240 WRITE (6,250)K
  250 FORMAT(7H0   K =,I8)
      WRITE (6,100)
      DO 260 I = 1,30
  260 WRITE(6,120)I,X(I),R(I),M(I),DP(I),DB(I)
      WRITE (6,130)X(31),R(31)
      GO TO 280
  280 CONTINUE
  310 STOP
      END
$ENTRY
$STOP
/*
//
```

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13. ABSTRACT

Shock-wave propagation and focusing theories were investigated in the U. S. Army Weapons Command Science and Technology Laboratory to determine the feasibility of utilizing shock waves for military applications. The propagation of hypothetical weak shock waves with small planar or concave frontal areas was analyzed on the basis of Whitham's shock-wave theory. The results indicate that shock waves with these characteristics cannot be propagated intact over militarily significant distances. The general applicability of Whitham's theory to this problem is questionable, however, in view of experimental data in the literature which indicate that very weak shock waves can be effectively focused. Therefore, these discrepancies should be experimentally resolved to explicitly define the feasibility of military applications of shock waves. (U) (Author)

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14. KEY WORDS	LINK A		LINK B		LINK C	
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5. Planar						
6. Concave						